Thermal and Optical Improvement of Light-Emitting Diodes with Mesh Pattern on Sapphire Back Delineated by Laser Etching

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Gallium nitride (GaN) blue light-emitting diodes (LEDs) [1] have been widely applied as the light sources for traffic signals, LCD screens, head lamp of automobiles and etc. However, poor heat dissipation and high-demanded optical efficiency for LEDs are the two major problems needed to be improved. The poor heat dissipation of conventional GaN/sapphire LED due to the low thermal conductivity of sapphire substrate leading to high LED junction temperature and degrades the LED performance. Flip-chip [2] and laser lift-off [3] techniques, which use high thermal conductivity substrates, were employed for replacing sapphire to decrease the thermal resistance. For high extraction efficiency, lots of the previous works such as p-GaN surface roughness [4], transparency electrode [5], patterned sapphire substrate [6] and photonic crystals [7] were used to improve the LED performance. The authors have built up mesh textured surfaces on the backside of sapphire of conventional LEDs, and following deposited high thermal conductivity material. Cooper for example, was filled into the mesh grooves to increase the effective thermal conductivity and therefore release spot heating problem from LEDs. The thermal conductivities of different materials in this experiment are shown in Table 1. Meanwhile, the backside mesh pattern could also enhance the light extraction efficiency by scattering or re-direct the light into escape cone. Consequently, both optical and thermal performances are improved simultaneously.

\ Materials	sapphire	Cu	Ag
Thermal conductivity (W/cm・K)	0.350	3.937	4.173

Table 1 Thermal conductivity of different materials in this work.

In this study, the GaN LED epilayers about 5 μm thick were grown on sapphire substrate by MOCVD. Fabrications of LED chips were accomplished by standard semiconductor processes. The sapphire substrate was lapped to 100 μm and then diced to 300 × 300 μm^2 for each single chip.

Usually, the dry or wet etching processes were used to form the groove pattern on sapphire. Both methods are chemical-related, time consuming and complicated processes. In this study, a simple, flexible and non-contact UV laser scriber with irradiation width of 10 ± 2 μm was used to etch the sapphire. The depth is 30 μm and the pitch is 30 μm. The E-gun evaporator was then used to evaporate Ag layer (0.5 μm) and Cu layer (30 μm). The process flow is indicated in Fig. 1. Figure 2 shows the sapphire surface with a meshed groove pattern after laser etching process.

After these processes, the I–V characteristics of LED were the same compared to conventional LED. It means that there is no damage during the process of laser etching. The heat dissipation was improved and the junction temperature reduced, and the higher light intensity is also achieved from the meshed groove pattern with metal materials coating.

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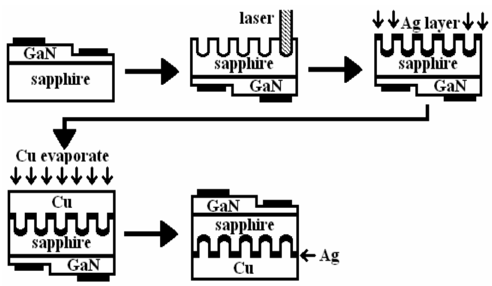

Fig. 1 The fabrication processes of GaN LED with meshed grooves and Ag/Cu thermal dissipation layer on its back.

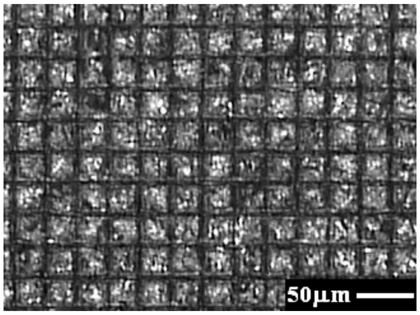

Fig. 2 The back surface of sapphire after laser etching.